

Research Article

Integrating herbarium data with spatial biodiversity assessment into conservation plans: A case study of the genus *Carex* L. (Cyperaceae) in Saskatchewan, Canada

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Abstract

Sedge (*Carex* L.) is the largest genus of vascular plants in Saskatchewan, Canada, where it is represented by 105 species. The aim of this study was to develop an effective procedure to assess the conservation status of sedges in the province. Data on 49 target *Carex* species were collected, validated, and consolidated from the Flora of Saskatchewan Association (FOSA) and the Global Biodiversity Information Facility (GBIF) datasets, resulting in 277 specimen-based occurrences. Applying a novel assessment approach, target *Carex* species were classified as follows: Critically Endangered (CR) – six taxa, Endangered (EN) – four, Vulnerable (VU) – eight, Near Threatened (NT) – three, Least Concern (LC) – 24, and Data Deficient (DD) – four. This allowed for a substantial reduction to a list of rare sedges compiled by the Saskatchewan Conservation Data Centre (SKCDC) from 40 species (38.1% in the genus) to 21 species (20.0%).

In terms of territorial protection, rare sedges (CR, EN, VU and NT conservation categories) have been recorded only in 13 or 4.0% of protected areas in Saskatchewan. Most sedges (12 species or 57.1%) have no recorded occurrences in the protected areas. This group is followed by five species (23.8%) found in a single protected area, three species (14.3%) recorded in two protected areas, and one species (4.76%) observed in three protected areas. Anthropogenic land use changes such as agriculture, urbanization, and industrial activities are the major threats to sedges in Saskatchewan. An effective action plan for the conservation of *Carex* species is crucial to reduce threats to this group of plants. Our results provide a scientific basis for the long-term conservation of sedge diversity in Saskatchewan.

Key words: Canada, *Carex*, conservation, distribution patterns, land use, occurrence datasets, protected areas, rare species



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Introduction

With global species decline occurring at an unparalleled rate due to anthropogenic activities, effective conservation of biodiversity is essential for human survival and the maintenance of ecosystem processes (Millennium Ecosystem Assessment 2005; Rands et al. 2010; Ceballos et al. 2015). Habitat destruction caused by land use is the main driver of biodiversity

loss globally (Haddad et al. 2015; Newbold et al. 2015; Fardila et al. 2017; WWF 2020). Effective mitigation of biodiversity loss requires approaches that integrate (i) data about the species' distribution and population size (IUCN 2024), (ii) spatial analysis to identify changes in species ranges due to land use (Moreira et al. 2024), (iii) habitat conservation through the establishment of protected areas (Watson et al. 2014), and (iv) conservation planning (Rodrigues and Gaston 2002).

In recent years, the IUCN Red List categories and criteria (IUCN 2012) have been increasingly used at the regional level. Assessing species at the regional level for their conservation is a vital first step in identifying and prioritizing species for both *ex situ* and *in situ* conservation actions (Kricsfalusy et al. 1999; Rodríguez et al. 2011; IUCN 2012). The regional conservation assessments and creating of Red Lists of threatened species are important to monitor the status of the biodiversity, increase the public awareness of the human impact on rare species, and enhance conservation planning and funding.

Recently, several studies have focused on identifying target species as key objectives for slowing the loss of biodiversity and filling gaps in conservation at national and regional levels in Canada (Coristine and Kerr 2011; Kricsfalusy and Trevisan 2014; Hardouin and Hargreaves 2023). These studies are particularly timely since habitat loss threatens more than three-quarters of Canada's nationally at-risk species (Woo-Durand et al. 2020), many of which have little range overlap with protected areas (Caissy et al. 2020). In Canada, all species at risk are categorized by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2024). The COSEWIC criteria for the national or N-rank status assessment are patterned after the IUCN scheme (Mooers et al. 2010). At the subnational level (S-rank), each province maintains a regional list of species at risk using the element ranks set forth by NatureServe (Faber-Langendoen et al. 2012). For example, the Saskatchewan Conservation Data Centre (SKCDC 2024) classifies species at risk in the province following a standardized, repeatable, and transparent procedure for categorizing the province's flora and fauna.

The genus *Carex* L. (Cyperaceae), commonly known as sedge, includes 313 species in Canada (Brouillet et al. 2010) and 105 species in Saskatchewan (Leighton 2012), making it the largest genus of vascular plants in the country and this province. The significant diversity of *Carex* species in Saskatchewan is evident in the high variation of their geographical distribution and habitat specificity (Danylyk and Kricsfalusy 2020; Kricsfalusy et al. 2025). Despite the wide distribution, sedges are not immune to threats, with habitat loss posing a significant challenge to their survival. Currently, 40 *Carex* species are listed at risk in Saskatchewan (SKCDC 2024), however a detailed analysis of their rarity, threats and effectiveness of the existing conservation measures is lacking.

The objective of this work on conservation assessment of the genus *Carex* in Saskatchewan was to: (a) identify species deserving protection in the province; (b) assess the current state of species conservation using multiple criteria, and (c) evaluate effectiveness of existing protected areas for species conservation. This research aims to further the considerations for selection of *Carex* species for conservation and monitoring efforts.

Materials and methods

Study area

Saskatchewan is a prairie province in Canada bordered to the west by Alberta, to the north by the Northwest Territories, to the northeast by Nunavut, to the east by Manitoba, and to the south by the United States (Montana and North Dakota). With a vast area of 651,036 km² (The Atlas of Canada, 2008), Saskatchewan is larger than any country located entirely in Europe. The province is bounded between Lat/Long 60.005850, -106.276263, in the north and Lat/Long 49.048044, -106.00548°, in the south. Saskatchewan has a temperate continental climate with hot to warm summers and cold winters, which means that the annual temperature range can be up to 75 °C. Saskatchewan is the sunniest Canadian province year-round (2206 hrs) and has the fourth-lowest total precipitation (428 mm). There is a significant difference in mean temperature and precipitation between the southwest and northeast parts of the province. Overall, there are warmer, drier conditions in the southwest and cooler moister conditions in the northeast of Saskatchewan.

Several biogeographic factors contribute to the richness and diversity of Saskatchewan's vegetation, which varies, depending on climate, soil and elevation. From north to south there are four ecological zones or biomes (Taiga Shield, Boreal Shield, Boreal Plain and Prairie) which are further subdivided into 11 ecoregions (Acton et al. 1998).

Data collection and validation

Distribution data were obtained by harnessing georeferenced specimen-based occurrences for 105 *Carex* species present in Saskatchewan from the Global Biodiversity Information Facility (GBIF 2020) and the Flora of Saskatchewan Association (FOSA 2022) datasets. The GBIF mobilised datasets represent important sedge collections for the province including the following herbaria: Canadian Museum of Nature (CAN), Marie-Victorin at the University of Montreal (MT), New York Botanical Garden (NY), University of Alberta (ALTA), Field Museum of Natural History (FMNH), University of Tennessee (TENN), National Museum of Natural History, Smithsonian Institution (USNM, US), McGill University (MTMG), and University of Michigan (MICH). Then, the GBIF datasets were combined with the Flora of Saskatchewan Association (FOSA 2022) dataset which contains data from the W.P. Fraser Herbarium at University of Saskatchewan (SASK).

The process of validation entailed taxonomic verification of *Carex* species against the Database of Vascular Plants of Canada or VASCAN (Brouillet et al. 2010) and the Plants of the World Online database (POWO 2024). The data filtering of the species occurrences was conducted to eliminate multiple entries by cross-checking the Flora of Saskatchewan Association (FOSA 2022) dataset with the Global Biodiversity Information Facility (GBIF 2020) datasets. To deal with the bias and mistakes in the occurrence data, several processes to manipulate the raw data were conducted. First, those records that had either no geographical coordinates or unclear taxonomic information were excluded. Second, those records that had duplicated coordinates were removed. Each validated species includes georeferenced points with an attribute table consisting of the sampling locations linked to the FOSA and GBIF datasets. Thus, from the existing distribution records of *Carex* species in Saskatchewan, in total

2655 occurrences of 105 species were validated which represents 2084 records from FOSA and 571 records from GBIF (Kricsfalusy et al. 2025). For this study 49 target *Carex* species were identified, which represents 277 occurrence records (212 records from FOSA and 65 records from GBIF).

Species selection

According to the SKCDC (2024), there are 40 *Carex* species at risk in Saskatchewan. Based on these data, there are no *Carex* species of global concern (G1–G3) in the province, five species are at risk at the national level (N1–N3) and 40 at the subnational (provincial) level (S1–S3). It should be noted that the same species can be placed in all three groups (global, national, and subnational) simultaneously. These *Carex* species with the subnational ranks are distributed within the following categories: Critically Imperiled/Extremely rare (S1) – nine taxa, Imperiled/Very rare (S2) – five, Vulnerable/Rare to uncommon (S3) – 19, Historical occurrence, without recent verification (SH) – five, Not Ranked, species have not yet been assessed (SNR) – seven.

In this regional assessment, a focus was placed on *Carex* species which present significant conservation priorities in Saskatchewan. For this purpose, 49 target species were engaged in an integrated analysis. First, out of 40 *Carex* species at risk listed by the SKCDC (2024), 36 species were selected for the spatial analysis. The four remaining species from that listing (*C. hallii*, *C. lapponica*, *C. pachystachya*, and *C. paleacea*), due to conflicting information on their taxonomy or occurrence in Saskatchewan, were classified as Data Deficient (DD) and not included in the spatial analysis. In addition to the 36 selected species, we introduced nine other species in the analysis (*C. arctogena*, *C. hookeriana*, *C. houghtoniana*, *C. laeviconica*, *C. lenticularis*, *C. meadii*, *C. oligosperma*, *C. pauciflora*, and *C. simulata*) with low occurrences (from two to eleven records) which were not included in the SKCDC (2024) assessment. Thus, a total of 45 *Carex* species (36 from the SKCDC listing and nine suggested in this study) were included in the spatial analysis (Fig. 1).

Conservation assessment

The IUCN classifies species based on five criteria A to E which are population decline, geographic distribution, small and declining population size, very small or restricted population, and quantitative assessment of extinction risk (IUCN 2022). For purpose of this study, we modified the IUCN approach to make it applicable in understudied regions with a lack of detailed species-specific information and potential of collection biases related to specimen-based occurrences. This will be explained in more detail in the next section.

The geographic range (Criterion B) was the key tool to evaluate the conservation status of the selected 45 *Carex* species. Under this category, B1 – Extent of Occurrence (EOO) and B2 (including modified sub-criteria B2a and B2biii) – Area of Occupancy (AOO) are widely acceptable statistics utilized for risk assessment. According to IUCN (2012, 2022), EOO is an imaginary boundary based on taxon present occurrence records in a defined area and AOO is the area within EOO which is occupied by a species, excluding cases of vagrancy. The recommended and acceptable standard grid cell width of AOO is 2 km or area 4 km² (IUCN 2022) which has been followed in this

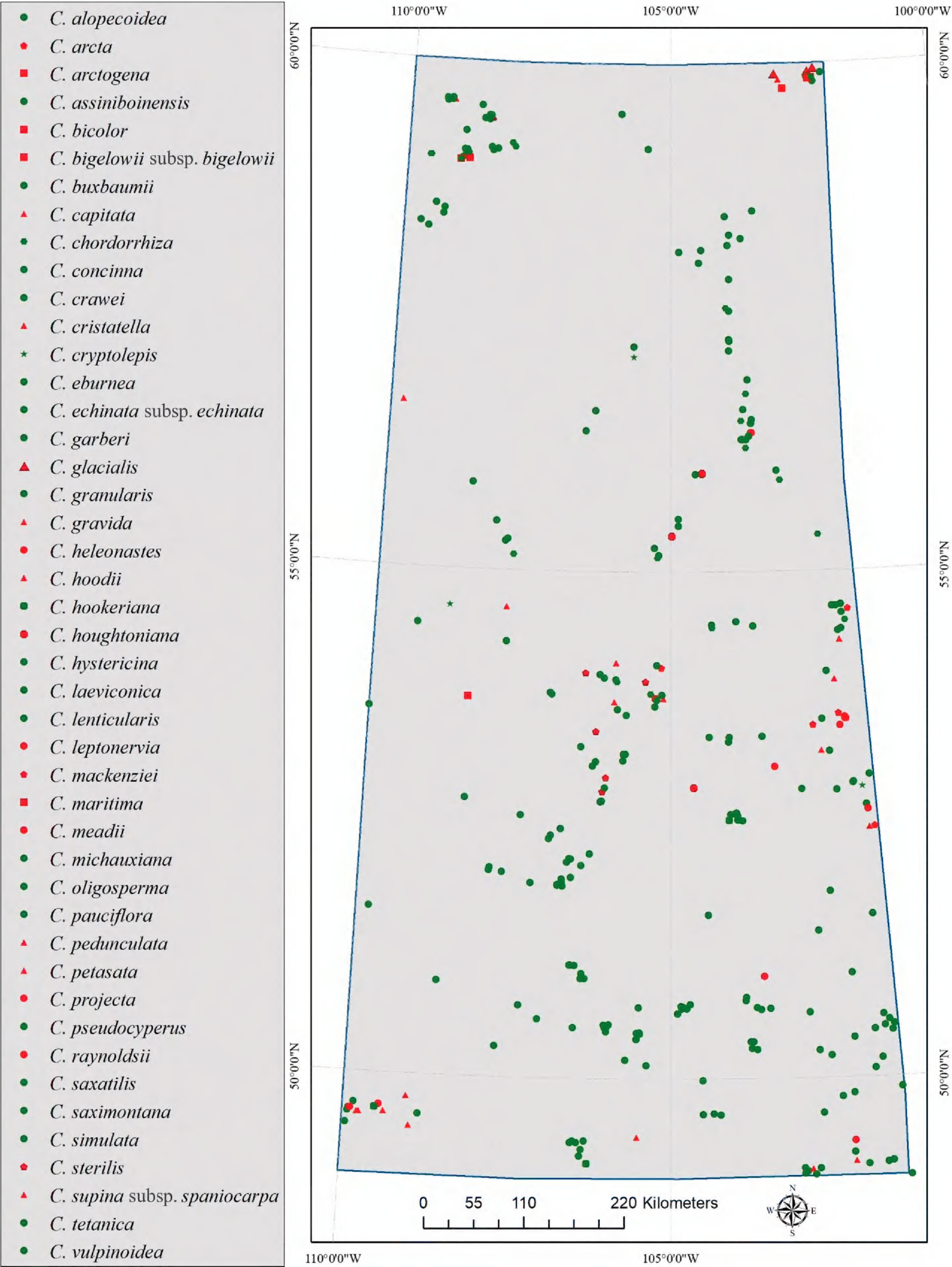


Figure 1. Distribution of selected *Carex* species in Saskatchewan based on the data retrieved from the Flora of Saskatchewan Association (FOSA 2022) and the Global Biodiversity Information Facilities (GBIF 2020) datasets. Red color code indicates rare *Carex* species (CR, EN, VU and NT conservation categories); green colour depicts species of Least Concern (LC). IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened.

study. EOO indicates the total area within which the species can be found, while AOO, based on a user defined cell width of 2 km, represents the projected area occupied by each occurrence.

To calculate EOO, and AOO we used Geospatial Conservation Assessment Tool (GeoCAT <https://geocat.iucnredlist.org>) for target *Carex* species by inserting collected occurrences or presence records (Bachman et al. 2011). If EOO was less than AOO, EOO was changed to make it equal to AOO to ensure consistency with the definition of AOO as an area within EOO following the IUCN (2022) guideline recommendation. In addition to that, preliminary designation of threatened categories of species was also identified using GeoCAT. The target *Carex* species were designated into the following categories: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC). Species can be designated based on its distribution area following criterion B threshold limit (IUCN 2024). Accordingly, CR category ranges EOO of less than 100 km² and an AOO of less than 10 km². EN category applies to species with an EOO of less than 5,000 km² and an AOO of less than 500 km². VU category applies for having an EOO less than 20,000 km² and an AOO less than 2,000 km². To qualify for the NT category, the taxon should be close to qualifying for the VU category. Species which do not fall under those criteria are considered as LC.

Species ranking

The calculated EOO (B1) and AOO (B2) for target *Carex* species were combined with number of Occurrences (B2a) harnessed from the FOSA (2022) and GBIF (2020) datasets (herbarium specimen-based records). An innovative three-point scoring system for each criterion was developed and used here. The range scores were assigned as follows: Critically Endangered (CR) – 3 points, Endangered (EN) – 2, Vulnerable (VU) – 1, Near Threatened (NT) – 0.5, and Least Concern (LC) – 0. In addition, sub-criterion B2b(iii) which integrates information on area, extent and/or quality of habitat was calculated. As is often the case, detailed species-specific information for this sub-criterion was not available. For such circumstances, Gauthier et al. (2010) suggested the method of criteria-establishment by combining different elements. With some improvement (Kricsfalusy and Trevisan 2014) this method was deemed to be highly relevant for rare plant species assessment in Saskatchewan. Therefore, a combination of two measures – Local Rarity (LR) and Habitat Vulnerability (HV) – from separate sources were used to quantify B2b(iii) sub-criterion using a five-point scoring system. First, a 2.5-point scoring scale was applied to LR and HV “components” separately and then pooled to obtain an overall score. To make up the LR component, a measure of regional distribution (species occurrences in ecoregions) was used. This score was pooled with the HV component that yielded a priority score for B2b(iii) sub-criterion. The HV component was standardized from the publication by Thorpe and Godwin (1999) ranking ecoregions of Saskatchewan according to the number of high-level (large extent and high severity) anthropogenic biodiversity threats they faced (Table 1). If a species occurred in an ecoregion(s) with threats of a greater extent and higher severity, it received a higher priority score. Oppositely, lower scores were assigned to species that occurred in ecoregion(s) that were less threatened by human activities. Thus, the priority scores were assigned as shown in Table 2. Finally, using a hierarchy of criteria

Table 1. Ecoregions of Saskatchewan ranking by habitat vulnerability.

Ecozone / Biome	Ecoregion	Threats level	Score
Taiga Shield	Selwyn Lake Upland	3	0.5
	Tazin Lake Upland	8	0.5
Boreal Shield	Athabasca Plain	5	0.5
	Churchill River Upland	15	1.0
Boreal Plain	Mid-boreal Upland	13	1.0
	Mid-boreal Lowland	15	1.0
	Boreal Transition	29	2.5
Prairie	Aspen Parkland	33	2.5
	Moist-Mixed Grassland	34	2.5
	Mixed Grassland	33	2.5
	Cypress Upland	27	2.5

Table 2. Criteria used to calculate the modified IUCN sub-criterion B2b(iii) integrating data on area, extent and/or quality of habitat for target *Carex* species in Saskatchewan.

Modified IUCN sub-criterion B2b(iii)	
Local rarity (LR)	Habitat vulnerability (HV)
Species exists in 1 ecoregion: 2.5 score	Species exists only in highly threatened ecoregion(s) (>27 threats): 2.5 score
Species exists in 2 ecoregions: 2 score	Species exists primarily in ecoregion(s) faced with high (>27) threats: 2.0 score
Species exists in 3 ecoregions: 1.5 score	Species exists in ecoregion(s) faced with high (>27), and/or moderate (13–15), and/or low (3–8) threats: 1.5 score
Species exists in 4–5 ecoregions: 1.0 score	Species exists only in ecoregion(s) faced with moderate (13–15) and/or low (3–8) threats: 1.0 score
Species exists in ≥ 6 ecoregions: 0.5 score	Species exists only in ecoregion(s) faced with low (3–8) threats: 0.5 score

species were ranked as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC).

Spatial analysis

The species distribution map (Fig. 1) is presented using 50 km x 50 km grid cells in accordance with the mapping approach suggested by Kricsfalusy et al. (2015). For this study, ArcGIS layers were developed using different data sources and plotted the presence records of *Carex* species. The geographical range of each species, EOO and AOO, were obtained in KML format from GeoCAT analysis and then converted into layers format in ArcGIS. Those layers were used as geographical range to identify protected areas as well as land cover types which fall under each species geographic range. It should be noted that all produced maps represent the record count (herbarium vouchers) and as such are a function of collecting bias. These maps may not be necessarily representative of true *Carex* species distribution in Saskatchewan.

To identify which protected areas fall under each species distribution, we obtained the latest data on protected areas of Canada from UNEP–WCMC and IUCN (2024). These data include a total of 11,885 protected areas that covers around approximately 12.1% of landmass and freshwater of the country (UNEP–WCMC and IUCN 2024). The shape file of Canada’s protected areas was clipped using administrative boundaries of Saskatchewan.

A total of 323 protected areas with 6,390,710 ha or 9.8% of land are contained within this Saskatchewan Protected and Conserved Areas Network (PCAN) (Fig. 2). The occurrences of rare *Carex* species (CR, EN, VU and NT conservation categories) were overlapped with the PCAN. Accordingly, all species found in the protected areas were identified. The number of occurrences of all species in the protected areas and the number of unique species were calculated. Based on that, a map of occurrences and richness in the protected areas for rare *Carex* species was developed (Fig. 3A, B).

In addition to the protected areas, distribution of rare *Carex* species was overlaid with land cover data to understand habitat affinities and potential threats to habitats. The land cover data for the province were obtained from Saskatchewan Digital Landcover (2023). According to this source, the land cover is categorized into agriculture, hay crops, native dominant grasslands, tall shrubs, pasture, hardwoods (open canopy), hardwoods (closed canopy), jack pine (closed canopy), jack pine (open canopy), spruce (closed canopy), spruce (open canopy), mixed woods, treed rock, recent burns, revegetating/regeneration burn, cutovers, water, marsh, herbaceous fen, mud/sand/saline, shrub fen (treed swamp), treed bog, open bog, farmstead, unclassified, barren land, mixed softwoods (open and closed), and pasture upland herbaceous graminoid (Fig. 2). The detailed descriptions of each class of land classification can be found in Saskatchewan Digital Landcover (2023). This layer was overlapped with species geographic range and from there, the habitats of target *Carex* species were identified. The overlap between species distributions, protected areas, and land cover types was quantitatively assessed using spatial statistics. For each species, the number and percentage of its distribution in the protected areas and different land cover categories was calculated. This allowed for comparisons across species and highlighting those most important protected areas and specific habitat types.

Results

Species ranges and conservation status

Table 3 presents the results of conservation assessment of the *Carex* genus in Saskatchewan completed for the first time by using an integrated approach. In total, 49 target *Carex* species were engaged in this assessment and 45 of them (36 from the SKCDC listing and nine suggested in this study) were selected for the spatial analysis. As previously mentioned, another four species were classified as Data Deficient (DD) and not included in the spatial analysis.

At first, the number of Occurrences (O) was calculated for each species. Among them, two species (*C. bicolor* and *C. heleonastes*) were found in a single location. The largest group includes 19 sedges, which are found in two to five locations. This group is followed by 11 species found in six to ten locations. The next nine species were found in 11 to 15 locations with the remaining four species recorded in 17 to 24 locations. Then, EOO was estimated based on IUCN standards which require at least three occurrences per each species to make a necessary calculation. As it turns out, along with single recorded species, nine species have less than three occurrences and EOO of those species could not be estimated. Following the standards (IUCN 2022), the EOOs of these species were set to the corresponding AOO values.

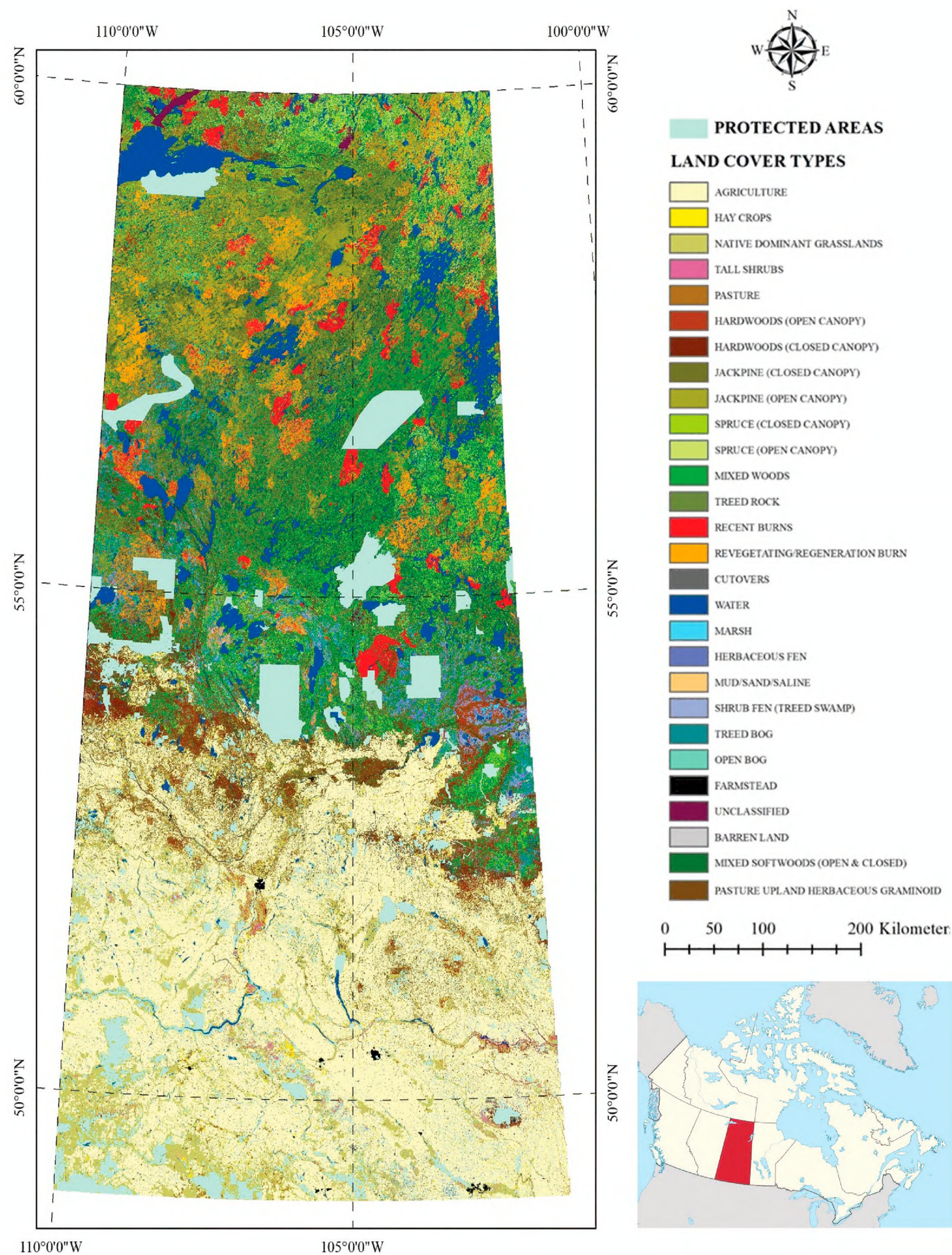


Figure 2. Land cover types and protected areas of Saskatchewan (Saskatchewan Digital Landcover 2023).

Applying the integrated approach based on the IUCN benchmarks (0, E00, and A00) and the modified B2(iii) sub-criterion, allowed to complete comprehensive conservation assessments of the genus *Carex* in Saskatchewan. As a result

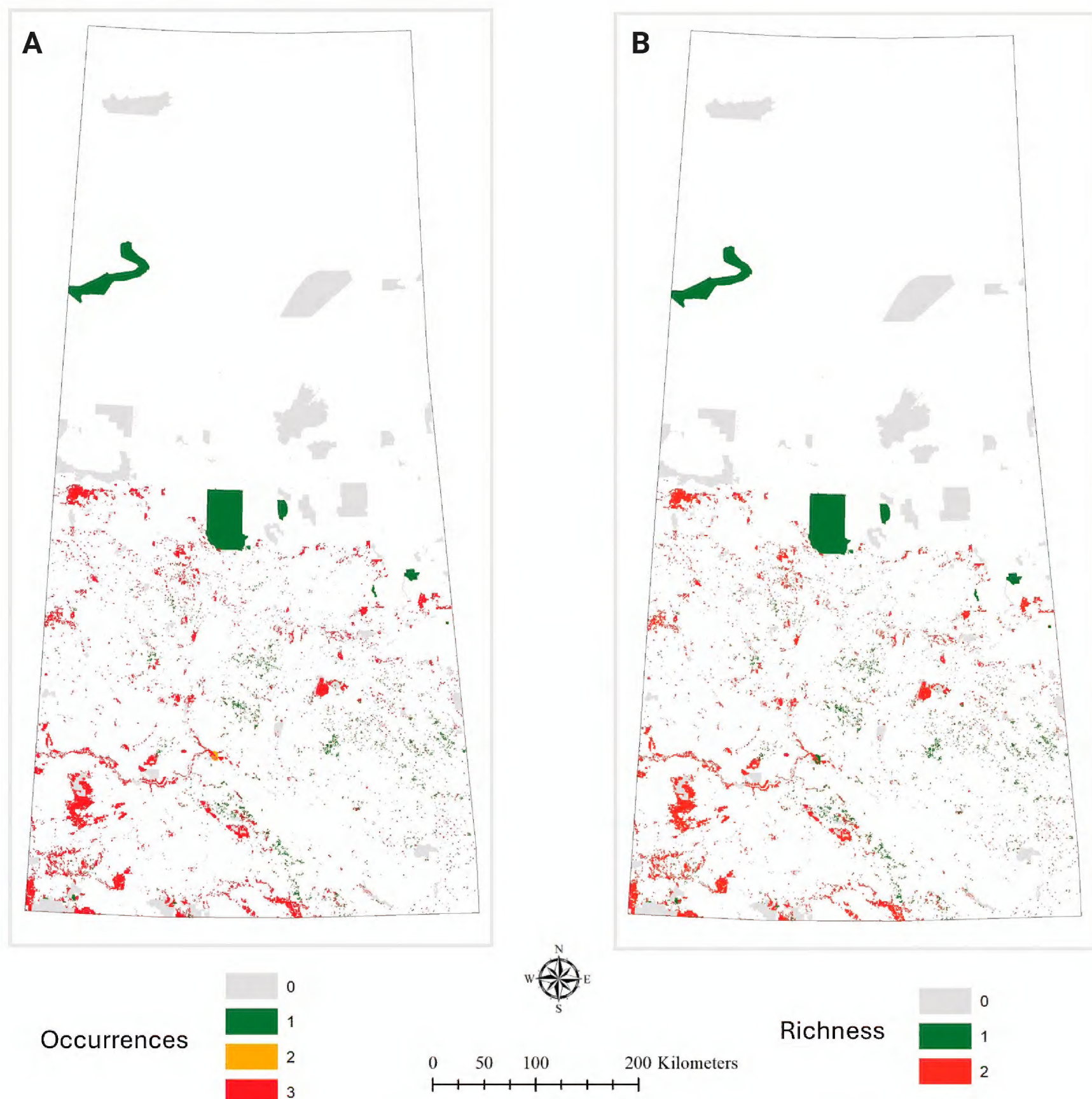


Figure 3. Map of **A.** Occurrences and **B.** Richness of rare *Carex* species (CR, EN, VU and NT conservation categories) in the protected areas of Saskatchewan. IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened.

of this analysis, target sedges were classified as follows: Critically Endangered (CR) – six species, Endangered (EN) – four, Vulnerable (VU) – eight, Near Threatened (NT) – free, Least Concern LC – 24, and Data Deficient (DD) – four (Fig. 4A). Using this novel approach, allowed substantially reduce the SKCDC (2024) list of rare sedges from 40 species (38.1% in the genus) to 21 species (20.0%). Compared to the previous SKCDC (2024) assessment, sedges have been substantially re-categorized by “downgrading” conservation ranks of most species (Fig. 4B).

Mapping over protected areas

From the analysed *Carex* occurrences in Saskatchewan, the presence of rare species (CR, EN, VU and NT conservation categories) in the protected areas was identified in the range of 1–2 species. The substantial number of rare sedges (12 species or 57.1%) have no recorded occurrences in the protected areas.

Table 3. Occurrence (O), Extent of Occurrence EOO), Area of Occupancy (AOO), subnational (provincial) conservation status, and presence of target *Carex* species in the protected areas of Saskatchewan. B2(iii)– pooled Local Rarity (LR) and Habitat Vulnerability (HV), OPA– occurrence in the protected areas. IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened, LC– Least Concern, DD– Data Deficient. NatureServe ranks: S1– Critically Imperiled/Extremely rare, S2– Imperiled/Very rare, S3– Vulnerable/Rare to uncommon, SH– Historical Occurrence/Possibly Extirpated, SNR– Not Ranked, NA– Not Available (suggested in this study).

Species Name	Modified IUCN criteria				Pooled modified IUCN criteria	IUCN category	SKCDC rank	OPA
	B1 (EOO)	B2 (AOO)	B2a (O)	B2b(iii) (LR+HV)	B1+B2+B2a+B2b(iii)			
<i>C. raynoldsii</i>	3	3	3	5	14	CR	S1	0
<i>C. meadii</i>	3	3	3	4.5	13.5	CR	NA	0
<i>C. heleonastes</i>	3	3	3	4	13	CR	S3	0
<i>C. leptonervia</i>	3	3	3	4	13	CR	S3	0
<i>C. mackenziei</i>	3	3	3	4	13	CR	S1	0
<i>C. projecta</i>	3	3	3	4	13	CR	S1	1
<i>C. arctogena</i>	3	3	3	3	12	EN	NA	0
<i>C. bicolor</i>	3	3	3	3	12	EN	SH	0
<i>C. bigelowii</i> subsp. <i>bigelowii</i>	3	3	3	3	12	EN	S1	0
<i>C. maritima</i>	3	3	3	3	12	EN	S1	0
<i>C. gravida</i>	2	2	2	4	10	VU	S2	0
<i>C. petasata</i>	2	2	2	4	10	VU	S2	0
<i>C. glacialis</i>	2	2	2	3	9	VU	SH	0
<i>C. pedunculata</i>	2	2	2	3	9	VU	SH	1
<i>C. cristatella</i>	1	2	2	3.5	8.5	VU	S1	2
<i>C. hoodii</i>	1	2	2	3.5	8.5	VU	S1	2
<i>C. capitata</i>	1	2	2	3	8	VU	S3	1
<i>C. supina</i> subsp. <i>spaniocarpa</i>	1	2	2	3	8	VU	SH	0
<i>C. arcta</i>	0	2	2	3.5	7.5	NT	S2	1
<i>C. houghtoniana</i>	1	2	1	3.5	7.5	NT	NA	2
<i>C. sterilis</i>	1	2	1	3.5	7.5	NT	S1	1
<i>C. cryptolepis</i>	0	2	2	2.5	6.5	LC	S2	1
<i>C. granularis</i>	0	2	1	3.5	6.5	LC	S2	0
<i>C. hookeriana</i>	0	2	2	2.5	6.5	LC	NA	1
<i>C. simulata</i>	0	2	1	3.5	6.5	LC	NA	2
<i>C. tetanica</i>	0	2	1	3.5	6.5	LC	S3	0
<i>C. hystericina</i>	0	2	1	3	6	LC	S3	2
<i>C. oligosperma</i>	0	2	1	3	6	LC	NA	3
<i>C. pauciflora</i>	0	2	1	3	6	LC	NA	4
<i>C. pseudocyperus</i>	0	2	1	3	6	LC	S3	1
<i>C. assiniboinensis</i>	0	2	0	3.5	5.5	LC	S3	0
<i>C. crawei</i>	0	2	0	3.5	5.5	LC	S3	0
<i>C. echinata</i> subsp. <i>echinata</i>	0	2	0	3.5	5.5	LC	S3	2
<i>C. laeviconica</i>	0	2	0	3.5	5.5	LC	NA	0
<i>C. lenticularis</i>	0	2	1	2.5	5.5	LC	NA	2
<i>C. saximontana</i>	0	2	0	3.5	5.5	LC	S3	1
<i>C. alopecoidea</i>	0	2	0	3	5	LC	S3	1
<i>C. saxatilis</i>	0	2	1	2	5	LC	S3	0
<i>C. vulpinoidea</i>	0	2	0	3	5	LC	S3	2
<i>C. michauxiana</i>	0	2	0	2.5	4.5	LC	S3	2
<i>C. buxbaumii</i>	0	2	0	2	4	LC	S3	2
<i>C. chordorrhiza</i>	0	2	0	2	4	LC	S3	0
<i>C. concinna</i>	0	2	0	2	4	LC	S3	0
<i>C. eburnea</i>	0	2	0	2	4	LC	S3	0
<i>C. garberi</i>	0	2	0	2	4	LC	S3	3
<i>C. hallii</i>						DD	SNR	
<i>C. lapponica</i>						DD	S1	
<i>C. pachystachya</i>						DD	SNR	
<i>C. paleacea</i>						DD	SH	

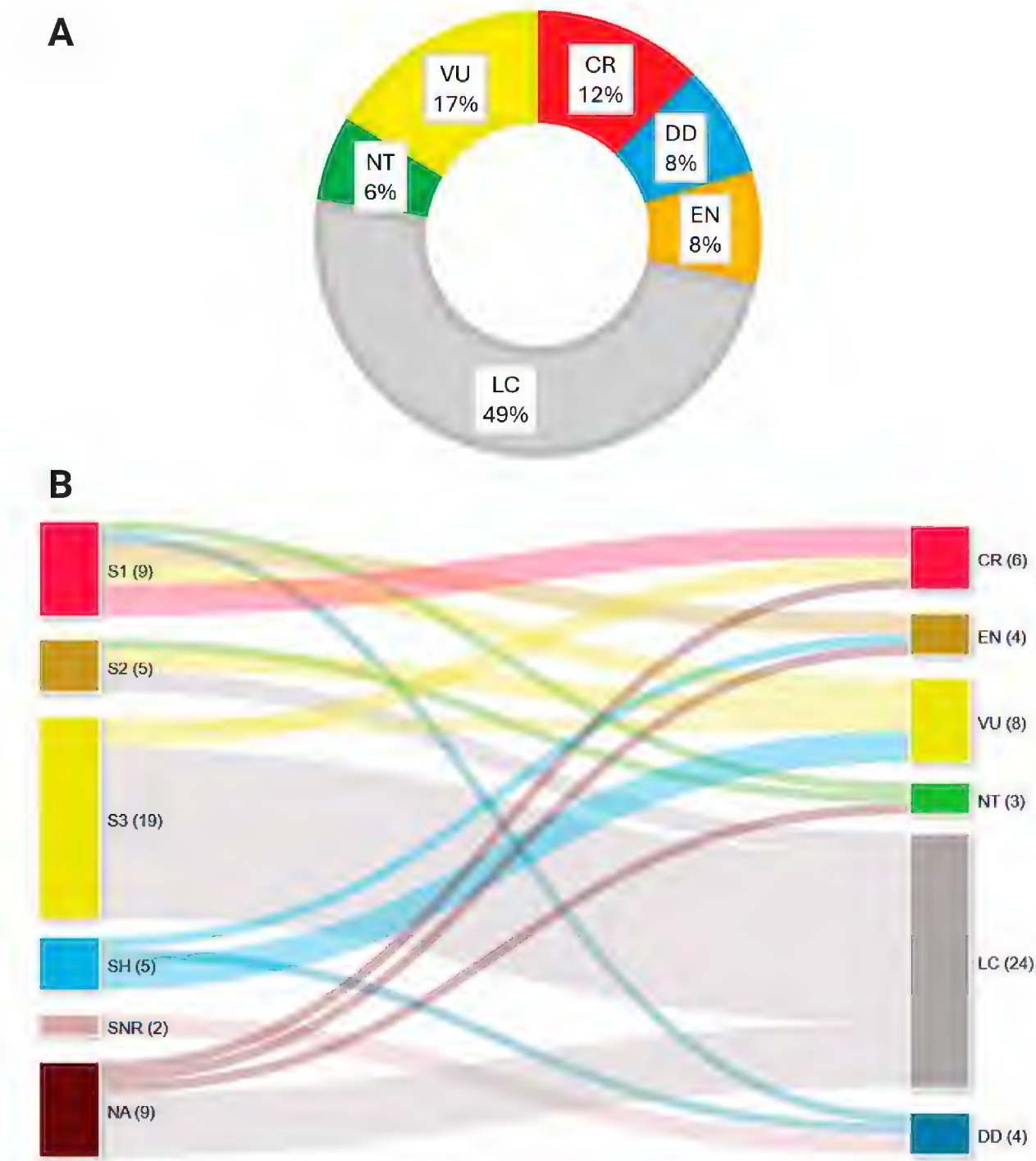


Figure 4. Summary of conservation status assessments and assessment changes for target *Carex* species of Saskatchewan. **A.** Doughnut chart summarizing the proposed assessments; **B.** Sankey diagram indicating changes from the previous assessment (SKCDC 2024) on the left to the proposed assessment on the right. NatureServe ranks: S1– Critically Imperiled/Extremely rare, S2– Imperiled/Very rare, S3– Vulnerable/Rare to uncommon, SH– Historical Occurrence/ Possibly Extirpated, SNR– Not Ranked, NA– Not Available (suggested in this study); IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened, LC– Least Concern, DD– Data Deficient.

This group is followed by five species (23.8%) found in a single protected area and three species (14.3%) recorded in two protected areas. The remaining species *C. garberi* stands out as the only species recorded in three protected areas.

Table 4 highlights the occurrence records and richness of rare *Carex* species within each protected area. A total of 13 protected areas were identified where sedges’ presence has been recorded. Among these, three of the protected areas are classified as Category II (National Parks), indicating they are designated primarily for ecosystem protection and recreation. Three of the protected areas fall under Category Ib (Wilderness Areas), where the focus is on preserving natural conditions with minimal human intervention. Two of these areas are categorized as Category V (Protected Landscape/Seascape), managed for landscape or seascape conservation and recreation. Additionally, one area is designated as Category IV (Habitat/Species Management Area), which are specifically managed for conservation through active interventions. One area is classified as Category III (Natural Monument), highlighting the protection of a specific natural feature. Lastly, one area is categorized under Category VI (Protected Area with Sustainable Use of Natural Resources), where conservation is integrated with sustainable

resource use. The number of categories of protected areas and species richness in each category are presented in Fig. 5. Occurrences of rare *Carex* species in the protected areas range from one to three, and richness one to two. In the Wildlife Habitat Protection (NA), highest *Carex* species occurrence (3) and richness (2) were found. On the other hand, Brockelbank Hill (III), Clearwater River Provincial Park (Ib), Connell Creek (Ib), Douglas Provincial Park (II), Great Blue Heron Provincial Park (V), Pike Lake Provincial Park (V), Prince Albert National Park (II), Private Conservation Lands (IV), Strawberry Lake (VI), Whiteswan Lakes (IV), and Wildcat Hill Provincial Park (Ib) were found to have single species occurrence and richness. In the Cypress Hills Interprovincial Park, two species occurrences and single richness were recorded. Based on the concentration of species or ecological metrics monitored, this will assist in determining whether places could be more ecologically relevant or demand further attention in conservation efforts.

Table 4. Recorded occurrences and richness of rare *Carex* species (CR, EN, VU and NT conservation categories) in the protected areas of Saskatchewan. O– occurrence, r– richness. IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened.

Protected areas (IUCN category)	O	r	Species recorded
Brockelbank Hill (III)	1	1	<i>C. cristatella</i>
Clearwater River Provincial Park (Ib)	1	1	<i>C. capitata</i>
Connell Creek (Ib)	1	1	<i>C. projecta</i>
Cypress Hills Interprovincial Parks (II)	2	1	<i>C. hoodia</i>
Douglas Provincial Park (II)	1	1	<i>C. houghtoniana</i>
Great Blue Heron Provincial Park (V)	1	1	<i>C. cristatella</i>
Pike Lake Provincial Park (V)	1	1	<i>C. houghtoniana</i>
Prince Albert National Park (II)	1	1	<i>C. sterilis</i>
Private Conservation Lands (IV)	1	1	<i>C. garberi</i>
Strawberry Lake (VI)	1	1	<i>C. garberi</i>
Whiteswan Lakes (IV)	1	1	<i>C. arcta</i>
Wildcat Hill Provincial Park (Ib)	1	1	<i>C. pedunculata</i>
Wildlife Habitat Protection (NA)	3	2	<i>C. garberi</i> , <i>C. hoodii</i>

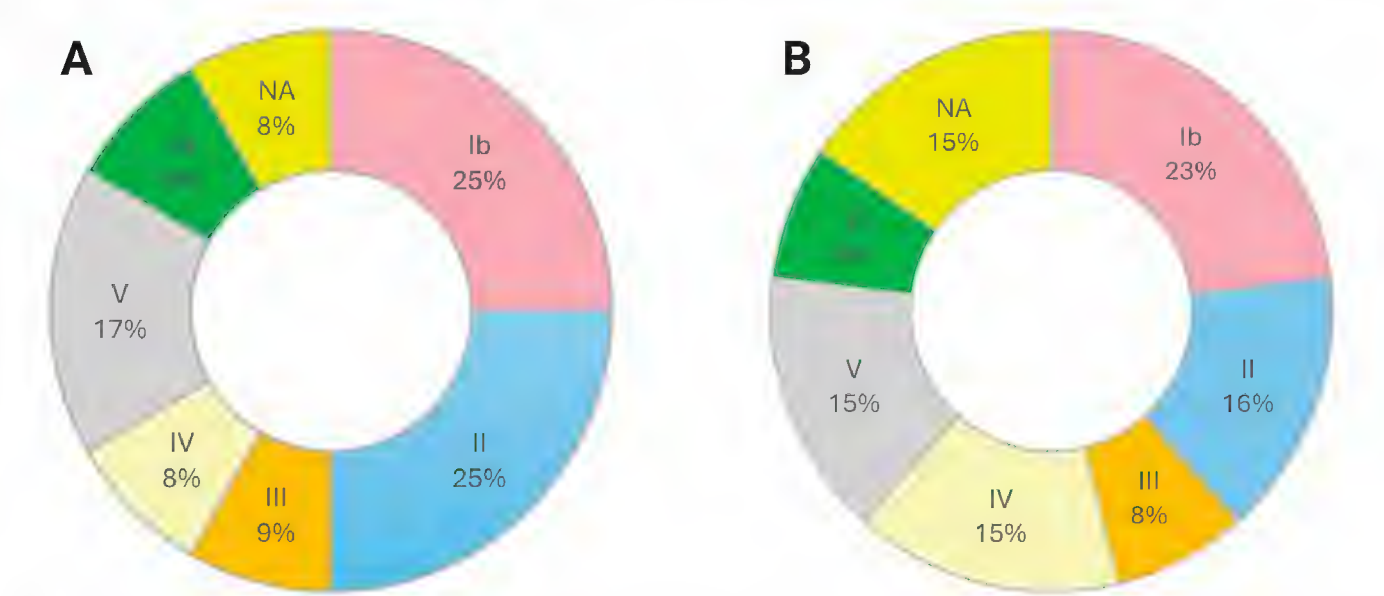


Figure 5. Doughnut chart showing the distribution of rare *Carex* species (CR, EN, VU and NT conservation categories) in the protected areas of Saskatchewan. **A.** Number of protected areas with rare species; **B.** Rare species richness in the protected areas. IUCN protected areas: Ib– Wilderness Areas, II– National Parks, III– Natural Monument, IV– Habitat/Species Management Area, V– Protected Landscape/Seascape, VI– Protected Area with Sustainable Use of Natural Resources, NA- Wildlife Habitat Protection. IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened.

Mapping over land cover

The obtained data on EOO and AOO (Fig. 6), mapped onto the land cover of Saskatchewan, provides a comprehensive understanding of the natural habitat coverage for rare sedges (CR, EN, VU and NT conservation categories), highlighting their environmental requirements across different landscapes. This analysis presents valuable insights into major occupied habitats based on EOO and AOO.

Among the different habitat types, the majority of rare *Carex* species (seven) primarily occupy agricultural areas within their Extent of Occurrence (EOO). However, EOO data could not be assessed for 12 species due to having fewer than three occurrence records. Based on Area of Occupancy (AOO), several rare species are distributed across multiple land cover types. *C. houghtoniana*, *C. sterilis*, *C. glacialis*, *C. pedunculata*, *C. supina* subsp. *spaniocarpa*, and *C. raynoldsii* are each associated with four or more habitat types, including mixed softwood forests, mixed woods, spruce forests, water bodies, jackpine forests, farmsteads, and cutover areas. In contrast, certain species (*C. leptonervia* and *C. mackenziei*) are confined to single habitat types, being recorded only in mixed softwood forests and shrub fen wetlands, respectively. *C. bicolor* and *C. bigelowii* subsp. *bigelowii* are found only in spruce closed canopy forests. *C. projecta* and *C. pedunculata* are associated with edge habitats, like hay crop fields and hardwood open canopy forests. *C. arctogena*, *C. arcta*, *C. capitata*, and *C. cristatella* are found in two or three different habitat types, including forested and wetland areas. *C. meadii*, *C. gravida*, and *C. petasata* are recorded in agricultural fields and grasslands.

Discussion

The comparison with the previous conservation assessment of the genus *Carex* in Saskatchewan (SKCDC 2024) indicates substantial changes of assigned conservation categories in the current assessment. Applying a novel approach, allowed to reduce a list of rare sedges compiled by the SKCDC (2024) by almost half (from 40 to 21 species). The obtained results should enhance efforts to create an effective basis for evidence-informed policy and decision-making, which remains crucial given increasing changes in land use in the province. Saskatchewan is one of the fastest growing provinces in Canada (Government of Saskatchewan 2023), resulting in increasing pressure on the existing natural habitats of many wildlife species, particularly sedges. Habitat loss and fragmentation, land use for agricultural purposes, rapid urbanization and rural expansion, and industrial mining activities were identified as major threats to *Carex* species in unprotected areas.

Agricultural land use leads to irreversible habitat transformation in Saskatchewan. It is estimated that almost 80% of the native grassland has been lost within the Prairie ecozone which contains 68 *Carex* species (Kricsfalusy et al. 2025), among them 5 rare species identified in this study. In local areas of prime cropland, less than 2% of the original habitat remains (Hammermeister et al. 2001). The most obvious changes in the prairie region are the fragmentation of native habitat caused by road building, residential development and cultivation. In the Boreal Plain ecozone, represented primarily by deciduous forests dominated by aspen conversion to agriculture, reached around 73% since European settlement. An annual deforestation rate is 0.89% over the last 28 years which is approximately three times the world average (Hobson et al. 2002). The Boreal Plain ecozone

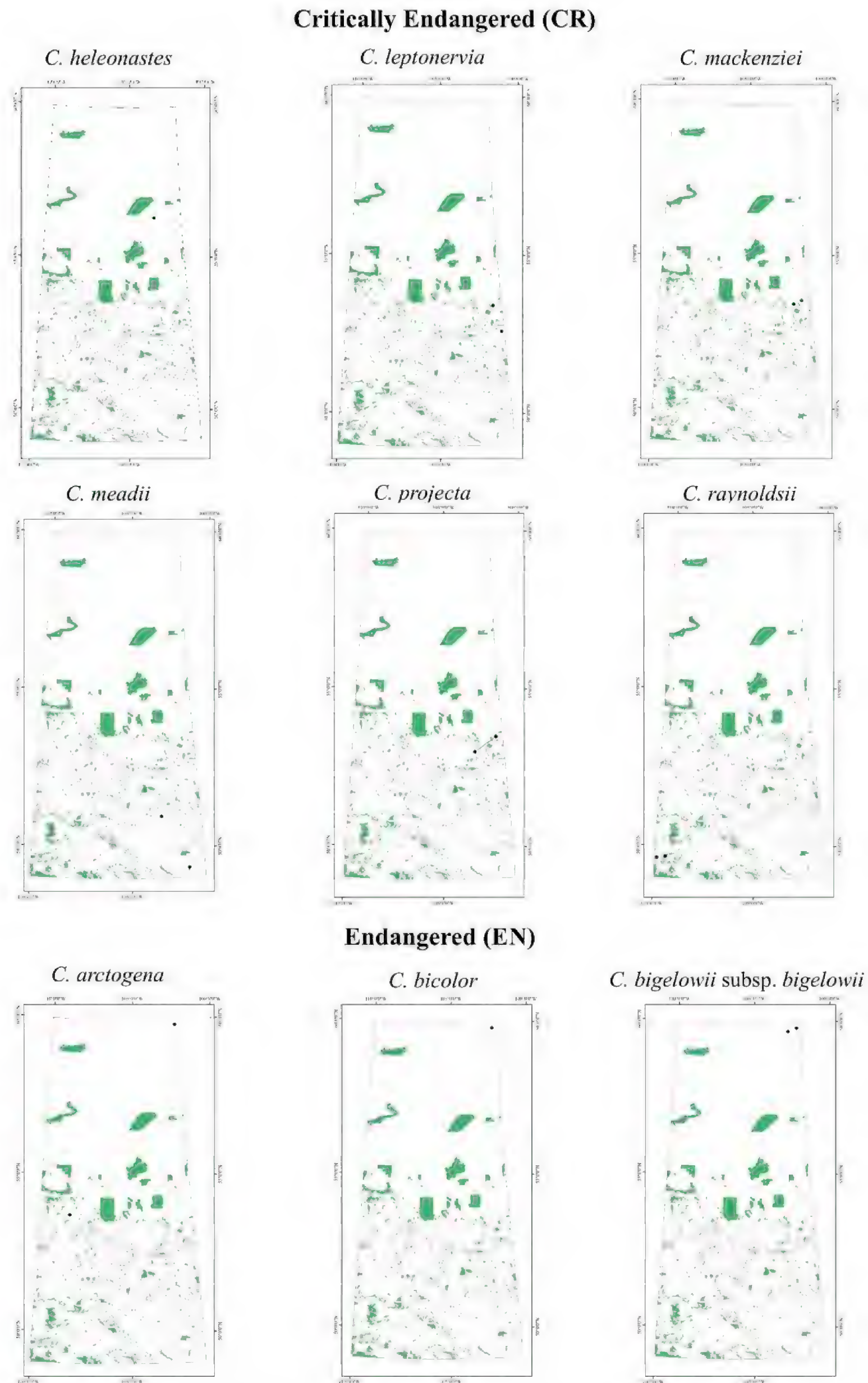


Figure 6. Occurrence (O), Extent of Occurrence (EOO), and Area of Occupancy (AOO) of rare *Carex* species (CR, EN, VU and NT conservation categories) that falls under the protected areas of Saskatchewan. The EOO is shown as a light blue minimum convex polygon encompassing all known occurrence points depicted in black dots. Green polygons represent officially designated protected areas. IUCN categories: CR– Critically Endangered, EN– Endangered, VU– Vulnerable, NT– Near Threatened, LC – Least Concern, DD– Data Deficient.

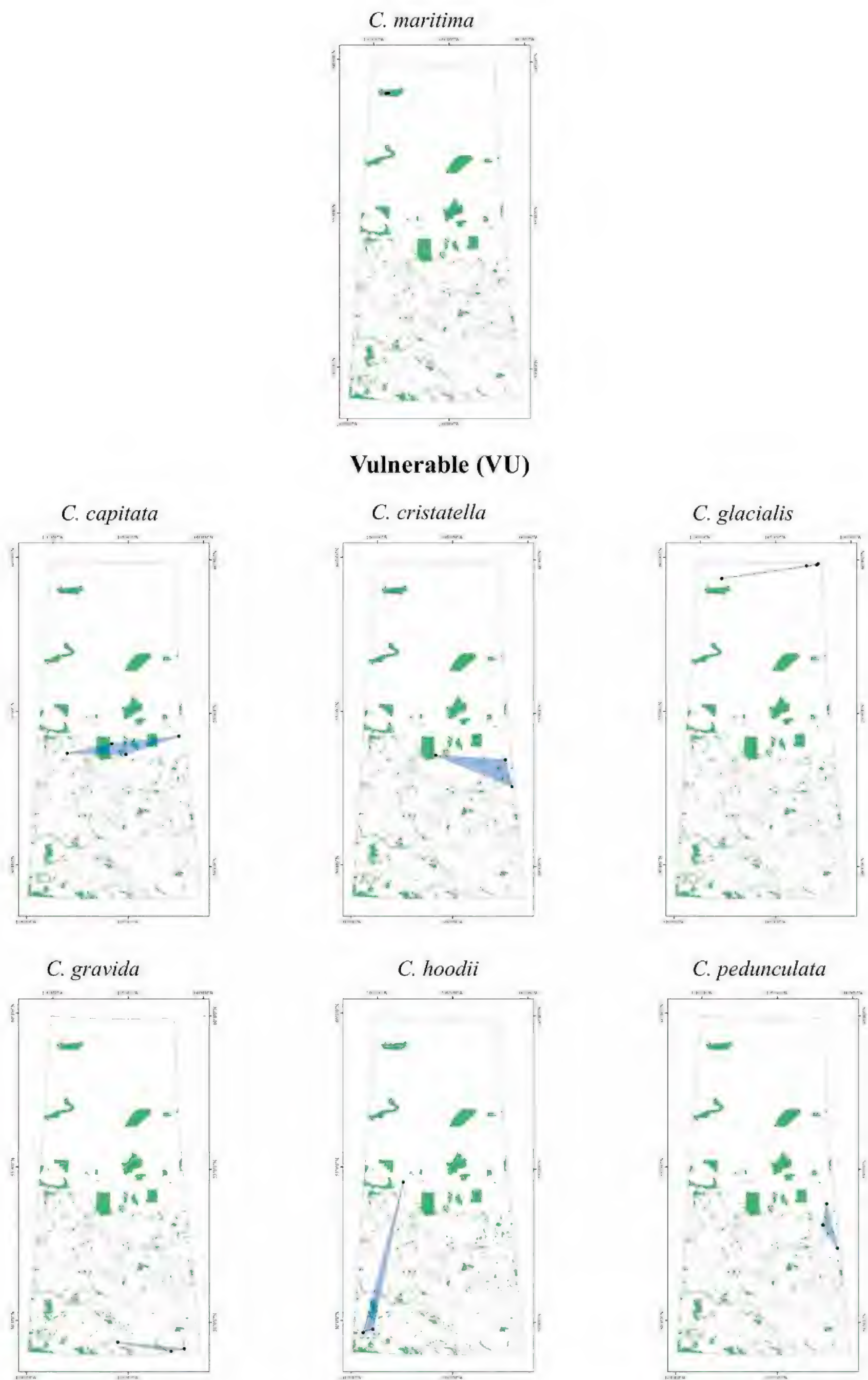


Figure 6. Continued.

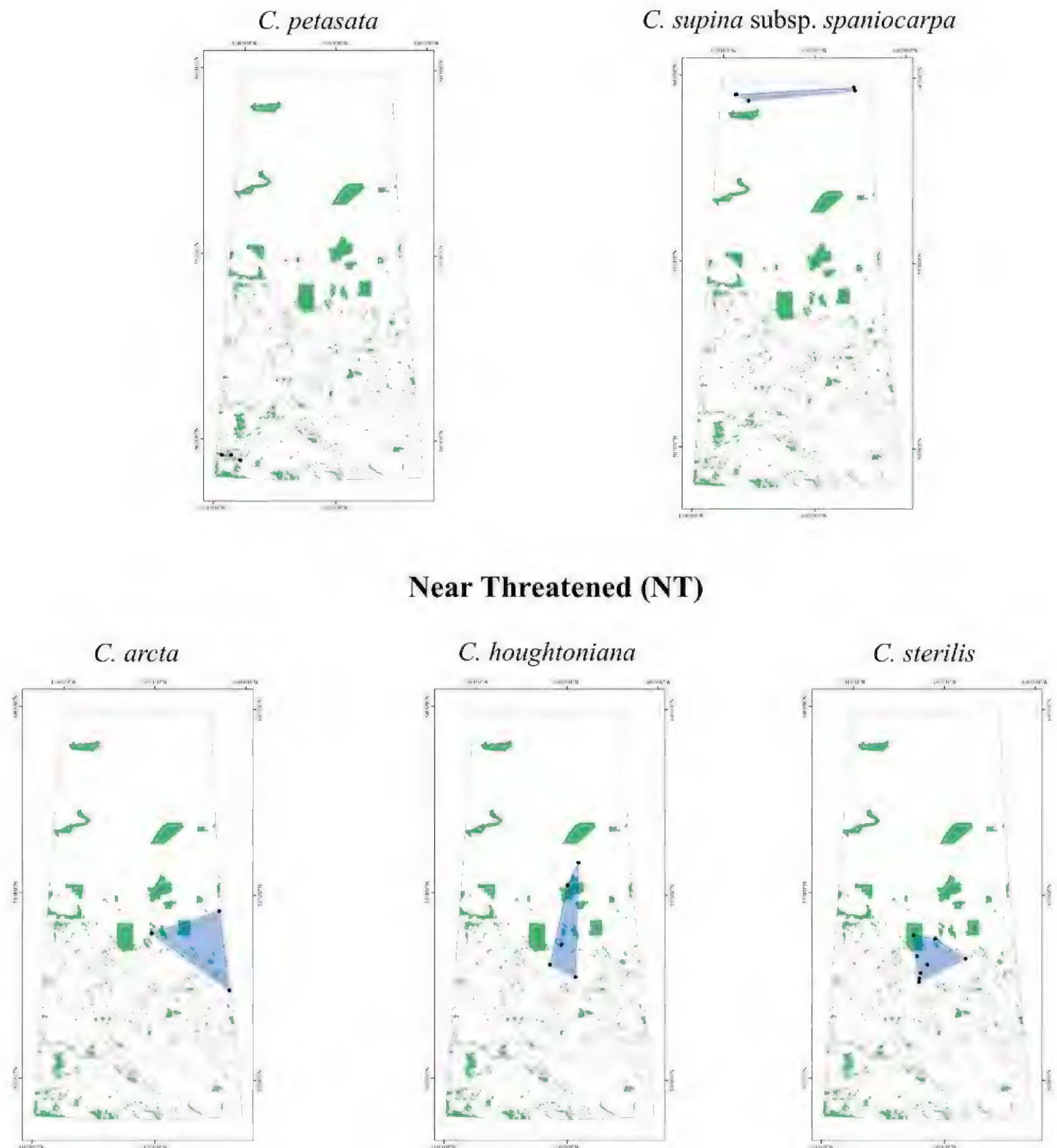


Figure 6. Continued.

is a major diversity hotspot for sedges containing 85 species (Kricsfalusy et al. 2025), including ten rare species, according to this study. The scale of land use for agricultural purposes in the boreal region has been constantly increasing over the past decade. Despite dramatic changes to forested areas and their importance to a wide variety of wildlife, no programs are in place to slow or halt deforestation.

Saskatchewan has a population of over 1.2 million people and continues to grow at its fastest pace in more than a century (Government of Saskatchewan 2023). The rapidly growing population has a strong effect on the province's flora and vegetation, including sedges. Urbanization and rural expansion are the second largest threat to *Carex* species conservation. These effects are especially detrimental in the areas around major urban centres like Saskatoon and Regina. In Saskatoon, threats from urban development and the recently built North Commuter Parkway in the Swales area resulted in habitat fragmentation, population decline of rare plant species, alteration of hydrological conditions,

and increased chemical and physical impact (Kricsfalusy 2021; Baijius 2024). Much of the area near Regina is cultivated or built up, while the native prairie has been almost lost (Roch and Jaeger 2014) including some important indigenous plants, like prairie crocus (*Pulsatilla nuttalliana* (DC) Bercht & J. Presl.). Conducted studies showed that densely built-up areas affect the species survival by reducing the extension of suitable habitat, fragmenting populations, and increasing edge effects (Esparrago and Kricsfalusy 2015). With the projected strong population growth in Saskatchewan in the upcoming years, the existing pressure on natural ecosystems will only increase.

Industrial mining activities in the prairie region (oil and gas exploration, potash and coal extraction) and in the boreal region (production of uranium and other minerals) are among the major factors increasing pressure on natural ecosystems in Saskatchewan. Historically, agricultural practices have had the most enduring impacts to the ecosystems. However, in recent decades the extraction of oil and natural gas resources have significantly altered the remaining native prairie through habitat destruction, oil and noise pollution, invasive species, and road infrastructure (Nasen et al. 2011). Mining also affects biodiversity at multiple spatial scales (site, landscape, regional) through direct (i.e. mineral extraction) and indirect processes (via industries supporting mining operations, and external stakeholders who gain access to biodiversity-rich areas as the result of mining) (Sonter et al. 2018). Saskatchewan ranks first in Canada for mining investment attractiveness, according to the Fraser Institute (2024). Thus, it can be expected that growing industrial activities such as mining, oil and gas operations, and infrastructure works will result in continuing habitat loss and fragmentation causing further decrease in biodiversity.

In terms of territorial protection of biodiversity, currently there are 323 protected areas or 9.8% of land in Saskatchewan which is below the national average of 12.1% for Canada and much lower than the goal set by the federal government of conserving 30% of country's land and water by 2030 (Government of Canada 2022a). According to this study, rare *Carex* species have been recorded only in 13 or 4.0% of all protected areas in Saskatchewan. The conducted analysis also revealed that 12 out of 21 species or 57.1% have no recorded occurrences in the protected areas, and another five species or 23.8% found only in a single protected area. In terms of preserving sedges, the most significant protected area is the Wildlife Habitat Protection (NA), where the highest sedges' occurrence (three species) and richness (two) were recorded. The rest of the province's protected areas where sedges have been found hold rather small number of *Carex* species occurrence (one-two) and richness (one).

Therefore, the existing situation requires optimization of the current Saskatchewan Protected and Conserved Areas Network (PCAN). Creation of Important Plant Areas (IPA) can be considered as an innovative approach to solve the problem of insufficient conservation of *Carex* species in the province. IPAs are defined as the most important places in the world for wild plant and fungal diversity that can be protected and managed as specific sites (Asaad et al. 2015; Plantlife 2018). The IPA approach is not widely accepted in Canada yet, however studies to identify IPAs have begun recently in Saskatchewan (Vinge-Mazer and Neufeld 2019). There is hope that the provincial government will use IPAs in its landscape planning approach to shift the focus to a habitat level. Another approach could be establishing micro-reserves, or a small-scale

plant protected areas as a part of the area-based conservation (Maxwell et al. 2020). Creating Other Effective Area-Based Conservation Measures (OECMs) is gaining popularity in Canada (Government of Canada 2022b). Both approaches could be a new dawn for conservation of *Carex* species in Saskatchewan.

Enhancing biodiversity conservation and monitoring through efficient management requires a culture change within the conservation community (Stephenson 2019). Equitable participation of data providers and users, including local communities, is central to the adaptive management process. This would ultimately enhance the efficiency, effectiveness and impact of biodiversity conservation and capacity building, including staff training and financial support. Training conservationists and the general public is vital for quality management. It might also help to increase iNaturalist observations which are very low for sedges compared to other vascular plants in Saskatchewan. The morphological appearance of *Carex* species can be confusing even for seasoned botanists. As a solution to this problem, we recommend organizing workshops on sedge morphology, distribution patterns and conservation issues. Summarizing all the actions presented above, a conservation strategy for the genus *Carex* in the province is an urgent task for the near future.

Conclusions

In this study, high-resolution specimen-based occurrences of 49 target *Carex* species in Saskatchewan were used to examine their distribution patterns within the provincial land use cover and nature protected areas to identify conservation effectiveness and gaps. In addition, threat analysis and collaboration with local botanists has supported the accurate conservation assessment. These efforts resulted in conservation ratings and detailed distribution maps for target *Carex* species in the province.

A novel assessment approach of the conservation status of the genus *Carex* in Saskatchewan using modified IUCN criteria was conducted for the first time. It allowed to substantially reduce a list of rare sedges compiled by the SKCDC (2024) from 40 species (38.1% in the genus) to 21 species (20.0%). Target *Carex* species were classified as follows: Critically Endangered (CR) – six taxa, Endangered (EN) – four, Vulnerable (VU) – eight, Near Threatened (NT) – three, Least Concern (LC) – 24, and Data Deficient (DD) – four. Compared to the previous SKCDC (2024) assessment, most sedges have been re-categorized by “downgrading” their conservation ranks. In terms of spatial conservation gaps, it was found that most rare *Carex* species (57.1%) have no recorded occurrences in the protected areas. Clearly, more conservation actions are needed to preserve rare *Carex* species including extension of the Saskatchewan Protected and Conserved Areas Network (PCAN). It can be substantially enhanced by introducing new conservation approaches, such as establishing Important Plant Areas (IPA) and creating Other Effective Area-Based Conservation Measures (OECMs), and culture change within the conservation community.

There are limitations to our study, primarily due to its reliance on documented herbarium vouchers of the *Carex* species occurrences, which is a function of collection bias as well as a shortfall in threat knowledge for certain taxon. Furthermore, changes in knowledge and the data sources may contribute to

changes in future assessment results. Additionally, conducted conservation assessment was based on geographic range (Criterion B) which provides a rapid regional assessment of the threats and only partially includes the human and economic forces that affect many *Carex* species in the province. Nonetheless, the obtained results allow quick and efficient procedure to understanding the conservation challenges and threats to this important plant genus in Saskatchewan. Overall, this study offers valuable insights into the conservation status, distribution patterns, and diversity of *Carex* species in Saskatchewan, laying a foundation for further conservation efforts and research endeavors in the province.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Vladimir Kricsfalusy: Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft preparation, Writing – review and editing. Kakon Chakma: Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft preparation. Austin Godfrey: Formal analysis, Software, Validation.

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Data availability

The data that support the findings of this study are available from the corresponding author upon request. Some data used in this study are available online (GBIF).

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